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Emergence of the small-world architecture in neural networks by activity dependent growth

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HIGHLIGHTS

- Activity-dependent neural network growth.
- Growth in neural networks leads to the formation of a small-world network.
- Time dependent neural network connectivity.
- Node degree distribution.

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ABSTRACT

In this paper, we propose a model describing the growth and development of neural networks based on the latest achievements of experimental neuroscience. The model is based on two evolutionary equations. The first equation is for the evolution of the neurons state and the second is for the growth of axon tips. By using the model, we demonstrated the neuronal growth process from disconnected neurons to fully connected three-dimensional networks. For the analysis of the network's connections structure, we used the random graphs theory methods. It is shown that the growth in neural networks results in the formation of a well-known "small-world" network model. The analysis of the connectivity distribution shows the presence of a strictly non-Gaussian but no scale-free degree distribution for the in-degree node distribution. In terms of the graphs theory, this study developed a new model of dynamic graph.

1. Introduction

As well as a wide range of other natural and technological networks, neural networks are characterized by a short path length, high clustering, heavy-tailed degree distribution, highly correlated and modular architecture [1]. Intriguing order and complexity of neuronal wiring make us think about the functioning of such networks, and also raise questions about how they develop with such an apparent precision. The progress in the theory of complex networks, caused by the discovery of scale-free [2] and small world [3] networks, has provided us with the new concepts and analytical tools that allow us to characterize and analyze the complex structure of the brain networks, and to connect them with the topological organization and function [4]. In terms of graph theory brain consists of small-world network's [3] and in the course of evolution process brain connections have been optimized to such a structure for efficient data processing [5]. However the processes underlying the emergence of a small-world connectivity in developing neural networks remain unknown.

Connections in neural networks are dynamic, especially during brain development when new neurons and connections between them are created. This process is continuous in life of the organism. The growing networks are self-organized

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